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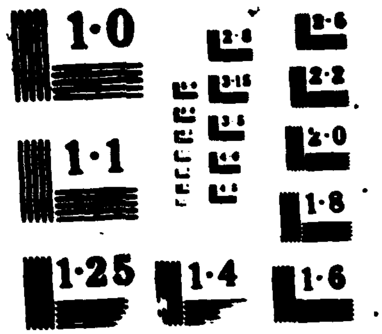
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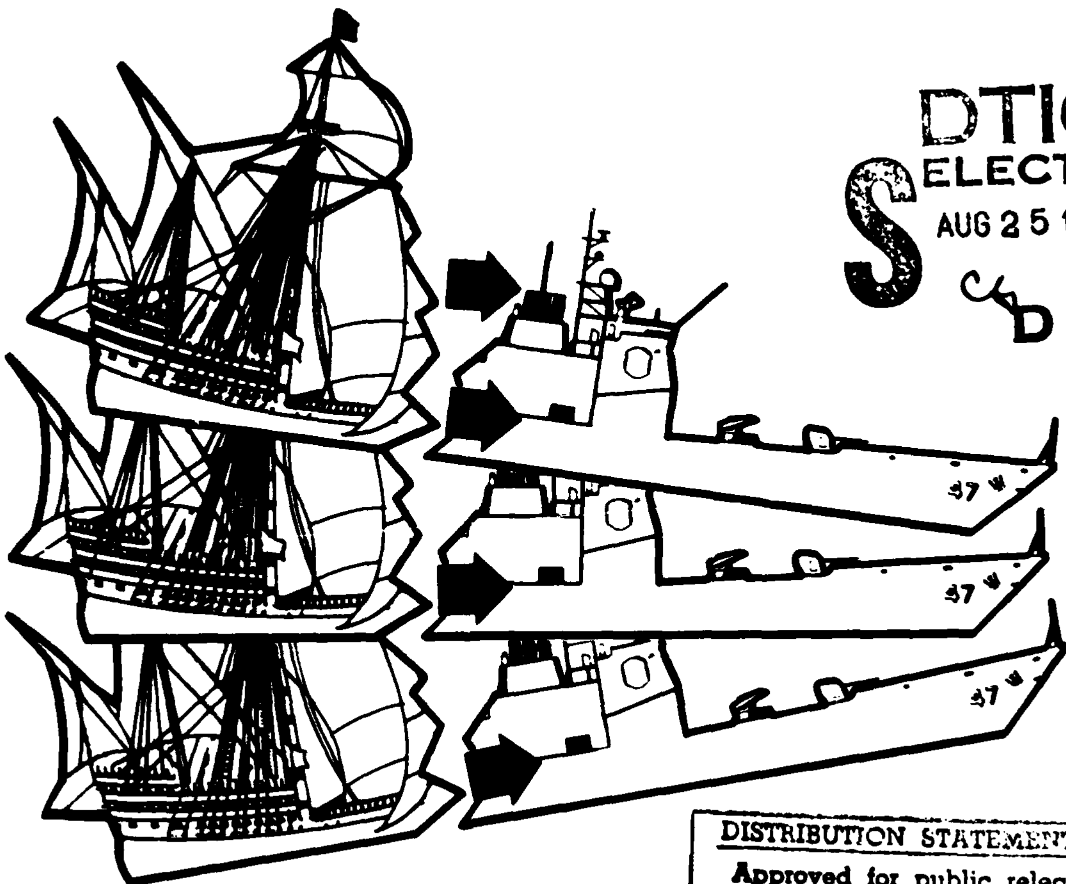

RECENT TRENDS IN SHIP SHOCK

by: James M. Fowler

ASSOCIATION OF SCIENTISTS AND ENGINEERS OF THE NAVAL SEA SYSTEMS COMMAND • DEPARTMENT OF THE NAVY • WASHINGTON, D.C. 20362

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ABSTRACT

The recent change from ship shock tests to ship shock trials is discussed including the differences between the two. The implication of this change is examined as it relates to equipment and system engineers. Shock trial unique preparations are presented.

BACKGROUND

Shock is indeed an insidious weapon effect. During World War II numerous naval ships on both sides were severely disabled due to near misses by bombs, by influence mines, or by torpedoes which missed their mark. During the Viet Nam conflict three US Navy ships were damaged by underwater explosions. What has the US Navy done to protect its ships from this effect? Actually, a great deal. As a result of joint Allied efforts during WW II lessons learned from war damage improved design features and construction practices to harden ships against shock. The US Navy implemented a shock qualification program for equipment utilizing shock test machines based on a British design. These machines are still in use today. In addition to qualification of equipment, the Navy sought to improve shock survivability through design and arrangement considerations. A Navy Mil Spec was established to standardize the qualification of these equipments. This spec, MIL-S-901, Military Specification Shock Tests, H.I. (High Impact); Shipboard Machinery, Equipment and Systems, Requirements For, was recently updated and will be issued as MIL-S- 901D. The improvements in the specification reflect the experiences of years of design and of ship shock testing.

In order to more fully understand the nature of underwater shock and its effect on ships, the Navy began a series of ship shock tests on both commissioned and decommissioned ships. These tests now number over 30. Figures 1 and 2 show the detonation from one of the ship shock tests. Today important changes are occurring that are of importance to the equipment and systems engineers as well as technical managers. It is these that this paper will address.

DISCUSSION

TRIALS vs. TESTS

In a large part due to the efforts of the AEGIS Cruiser Acquisition Project Manager (PMS 400), the Navy has moved away from ship shock tests and is now conducting ship shock trials. The difference is far more than just what we call the evolution. The main objective of a test is to see what happens. As such, limited pre-trial hardening efforts are undertaken. The concept of "shoot and see" is very much a part of the shock test philosophy. A trial on the other hand is intended to demonstrate and prove capabilities that have been designed into a ship. Validation and verification of hardening actions are demonstrated or proven during trials. Recent OPNAV shock policy (OPNAVINST 9072. Shock Hardening of Surface Ships) defines a test as technically oriented exercise intended to define shock survivability problems in scientific or engineering terms. A test seeks to get a better understanding of what is happening and advance the state-of-the-art for shock hardening. A trial on the other hand is intended as a demonstration/validation of the ability of a ship or system to operate in a combat shock environment. This same policy now directs that ship shock trials be conducted on the lead or an early ship of the class. As shown in figure 3, an ambitious schedule for shock trials has been established. Further, work is now underway to conduct additional single shot trials against all new construction deliveries.

Trials are conducted as a demonstration that the systems and equipment that have been installed can function as they are supposed to in as close to a wartime situation as possible. As a result a conscious effort is made before a trial to identify potential deficiencies and take corrective action to ensure the success of the trial. As a result pre-trial planning and preparation has increased in both scope and complexity.

PRE-TRIALS PREPARATION

The concept of taking conscious pre-trials actions to ensure success of the trial is a major feature of the shock trial relative to the shock test. As with other trials, the capabilities of a ship must be proven and demonstrated. What this means is that equipment or systems engineers must be prepared to have their systems work before, during, and after shock. Of course qualification testing to MIL-S-901 is required.

As a requirement it is not something to be feared or avoided. A part of the pre-trials preparation is to ensure that qualification testing has been done. The Navy is developing an automated data base for shock qualification status to aid the ship shock trial planning. In cases where qualification has not been accomplished, efforts are made to do so before the trial or to take hardening efforts which improve the chances of success. The requirement that unqualified equipment receive official waivers stems from the fact that shock hardening represents an OPNAV military requirement.

However, shock qualification of specific equipment is not the end of the road. In general equipment does not stand alone but is part of an overall system. As such, consideration must be given on a systems level as well. Unfortunately, while equipment criteria are well understood, system criteria are just now beginning to be comprehended. It is possible for all of the equipment in a system to be qualified and yet the system still will not function during combat. Numerous things contribute to this problem. In many cases the failure is the result of failing to take a systems approach by ensuring that the equipment interactions are considered during design. As a result the first time systems are demonstrated under shock is during a shock trial. It must be noted that ship shock trials are not intended and should not be expected to substitute for qualification testing.

Ship shock trials have provided many lessons in system shock qualification. One of those lessons is to make things as simple as possible. Designing for human engineering or lack thereof is often a facet shown by shock trials. Sailors who are under the pressures of combat may not have the time to deal with the intricacies of complex systems. It is often shown that the more complex systems are, the easier it is for something simple to cause major system problems. Systems which work well in laboratories or shore establishments do not necessarily do well at sea where the technical support is not easily available. System design for shock must consider all parts of the system and ensure that no single point of failure can cause the system to be rendered inoperable. The interaction of equipment within a system must be considered to ensure that the response of one piece to shock such as a power surge does not cause problems for other equipment within the system. It is often this interaction between parts of a system that are exercised under shock for the first time during a trial and found lacking. A systems approach for shock also requires that the responses of interfacing systems be considered and that the expectations be reasonable. For instance is not reasonable to expect structural supports to remain motionless. As a result systems designers must make allowances for relative displacements. In addition to these considerations the systems designers must learn to balance often conflicting requirements in a manner that does not jeopardize shock performance.

REQUIREMENTS

One of the requirements which has led to a number of problems in ship shock trials is that of peacetime safety interlocks and equipment protective devices. It is not suggested that safety is not important. On the contrary, safety is the major concern for shock trials conduct. What is being said is that the peacetime interlocks and protective devices for routine steaming and maintenance must not be allowed to interfere with the needs of the fleet to operate in combat. In many cases interlock mechanisms are tripped as a result of combat shock. Unfortunately designers usually design for peacetime. This is not always their fault as many of our specifications are peacetime oriented. As ship shock trials have demonstrated, the peacetime attitude needs to be replaced by a fighting ship attitude.

Another requirement which has indirectly caused problems is that of ensuring the maximum life of equipment or systems. This is usually done by ensuring that the optimal operating parameters exist. To do this, cooling and power requirements are established which provide for the best and longest operation of equipment. Often sensors are built in which cause equipment to automatically shut down if these parameters are exceeded. Under combat shock these sensors may give erroneous readings or the support systems may not provide the ideal cooling or power. In other cases little or no consideration is given to alternate sources of power or cooling. As a result attention is not given to degraded modes of operation whereby reduced capability is considered preferable to no capability at all. These thoughts make sense but are often not considered during equipment/system design and integration because of apparent "peacetime priorities".

As a result of these two requirements, the concept of "Battle Short" has been developed. Often during pre-trials this concept is worked into equipment and systems. Although a complete treatment of this concept would require more space than this paper allows, a brief discussion of the philosophy behind battle short is provided. Some examples of what has been and is being done are also provided. Battle short is based on the precepts that routine maintenance is not required during combat, that systems degradation is preferable to systems shut down, and that systems/equipments can and will operate in combat under less than ideal conditions. As a result, under battle short, cabinet electrical interlocks which shut the equipment down when doors are opened are disabled. Temperature or air flow sensors which are set for ideal requirements are examined to determine if the equipment can operate for a finite period of time with higher temperatures or less air flow. The long term effect might be shorter life but the equipment has a better opportunity to operate in combat. As a result temperature or air flow sensors may have the automatic bypasses disabled or modified. This allows for higher operating temps for a finite period of time. A key is to ensure that the operator still knows that the condition exists. In some cases the evaluation leads to the determination that the equipment could operate at less than full capacity for a long period of time. In that case degradation is preferable to shut down so automatic shut down must be overridden. This concept must be expanded and incorporated into more equipments and systems including the mechanical and electrical systems. In general battle short must be consciously engaged by the operator and some sort of warning device provided so that the operator is told that interlocks are disabled. The time to consider these capabilities is during design while we have a peacetime opportunity to prepare these systems for combat in an orderly way.

QUALITY ASSURANCE

Quality assurance is another area which rears its ugly head during shock trials. During shock tests the failures resulting from QA are just an inconvenience. During shock trials these failures can be disastrous. Even the best engineered designs can fail as a result of QA faults. For example power outages caused by a nut left by a workman in a power distribution panel during a recent shock evolution rendered many vital and otherwise shock capable systems useless. In order to reduce the chances of QA creating a problem, training of shipyard and SUPSHIP personnel has been undertaken to teach them what is and what isn't good shock practice. There are a number of initiatives underway now to ensure that this type of training is not limited to ships being readied for shock trial. Another step in assuring QA and in heading off installation caused problems is the conduct of a series of pre-trials inspections. These inspections hopefully occur early enough so that problems which are identified can be corrected prior to the trial. The concept of shock specific inspections for ships other than those being prepared for trial has been applied by the cruiser acquisition project who ensure that all new construction ships get at least two inspections prior to delivery. But these efforts are not enough. The designers must also take some responsibility for QA. One must make every effort to "design out" the sensitivity to QA problems. In cases where this can not be done the designer needs to get involved in establishing QA standards. It can be argued that designers should also be responsible for identifying potential QA problems as well as potential solutions. Systems engineers are responsible for ensuring that system specifications reflect good shock practice in clearly stated and achievable requirements.

An example of what an engineer can do to reduce the potential for QA problems is to use standardized materials and processes for construction. Of course the more complex the installation the more likely the chances are that there could be a problem in the installation.

BRITTLE MATERIALS

Closely related to quality assurance is the use of brittle materials. The generally accepted Navy definition of "brittle" is material that can not be elongated by a distance equal to ten percent of its original length without breaking. Under shock these materials often fail. Not all materials with limited ductility will fail, but given the required quality assurance during manufacture their use is discouraged. Cast aluminum is the major offender. Its use in applications which should be able to perform under shock is strongly discouraged. It should be noted that aluminum alloys such as AL MAG have proven to be useful in shock applications. The performance of cast iron has been so bad that it is generally forbidden on combatant ships. Glass of course is brittle and fiberglass tends to behave in a brittle manner so its application should be carefully considered. In addition ultra high-strength steels (those with yield strengths over 200,000 PSI) tend to be brittle.

COMBAT READINESS CARDS

Associated with QA is the need to ensure that maintenance requirements and subsequent close up procedures are clearly stated and reasonable. In many cases a piece of equipment that is shock qualified is specially groomed for qualification. This usually means that all the holdown bolts are properly torqued, all of the enclosure screws or bolts are in place and that all holdown bars for circuit cards are properly adjusted. Unfortunately, due to routine maintenance, this is not the way that equipments come to a shock trial. A major result of going from shock tests to shock trials is the acceptance and use of Combat Readiness Cards (CRC's). Combat Readiness Cards are intended to provide the information necessary to return the equipment to its groomed condition. In some cases these cards have been integrated into the MRC system as conditional use items. This grooming of equipment has become necessary in part because designers have again failed to consider the maintenance requirements and the real world in their design. For example, an equipment designer utilizes twelve screws to secure a panel cover which a sailor must open to do maintenance. If this piece of equipment requires fairly regular access it is unlikely that more that about half of the screws will be put back. The designer needs to consider not depending on the crew any more than necessary to keep his design from falling apart in combat. In addition the designer and arranger needs to consider access for equipment. If holdown bolts are not readily accessible it is unreasonable to expect ship's force to ensure that the bolts are properly tightened or even installed. In general, designers are oblivious to the role of maintenance in the survivability equation. A benefit of shock trials is that designers interest has been awakened in this area. Training designers to consider these areas is an ongoing effort.

SHOCK AWARENESS TRAINING

In an effort to improve crew awareness of this and other shock areas a program of crew training is being developed by NAVSEA. This training has been an evolving process. The current training consists of shock awareness and operational training. The shock awareness is presented in the form of video tapes and an "Illustrated Guide to Combat Shock" which are being prepared by NAVSEA. Some sample pages from the guide are shown in figures 4 and 5. The guide has been developed to provide reinforcement of the areas covered by the video tapes. The video tapes are in three modules covering shock trial overview, shock trial safety and shock trial inspection and reporting procedures. Also, briefings are held with ships force in order to answer any questions which might come up and to provide any ship specific training required. Operational training is usually conducted by fleet training representatives. Some additional training is often provided to ensure that the ship is proficient in the combat systems operational test procedure that is developed for the trial. With this training, ships force is ready to conduct the trial and "fight the ship" through.

THE SHOCK TRIAL

Following each detonation the ship goes through a period of "fighting the ship". It is during this period that ships force operates their equipment as if they were in actual combat. The concept of fighting the ship is one of the unique features of ship shock trials. As a result, complex operational plans and scenarios are developed to operate all ship systems. Fleet support for aircraft and sea assets are utilized to provide live targets for combat system evaluations. Following a specified period of time, detailed inspections are conducted to determine if any damage occurred which may not have been apparent to the operators. Many times the ship is underway but not making way during the actual shot. Therefore all the mechanical systems are up and running. Work is currently in progress to develop the capability to conduct shock trials with the ship underway and making way. Regardless, the ship gets put through what is sometimes referred to as a mini sea trial. Following this, a period of time is set aside for post-shot checkout including additional systems tests. This period is also utilized to repair any damage which may have occurred, to investigate damage reports and to document results prior to the next shot. During this period, preparations for the next shot also take place. Equipment that has been opened up is closed up and the integrity assured. Systems are at baseline so that their post-shot performance can be accurately measured. Upon completion of the last shot the same type of work is done so that deviations which might have been missed otherwise are noted. The ship then returns for a repair availability to restore the ship to its pre-trial condition. The inspectors and engineers begin the important phase of reporting and evaluating the results.

POST-SHOCK TRIALS FOLLOW-UP

Once the shock trial has been completed, the next and possibly most important phase of engineering begins. We have shown ourselves to be good at blowing ships up and not so good at getting the lessons learned into the fleet. The need for and importance of implementing lessons learned from shock trials is reflected in the OPNAV policy which requires that a funded follow-up action plan be approved and in place prior to the conduct of the shock trial. Following the trial semi-annual reports are made to OPNAV to show the progress being made in correcting the deficiencies. The attitude for trials of making changes prior to trial and insuring that changes are not just for the ship being shocked is a major step. In support of the post-shock trials engineering efforts a conscious effort is made to retain failed parts from the trial for further analysis. Coordination of the follow-up efforts needs work but is improving. The Navy is automating its data base on shock trials so that lessons learned can be made available to designers and engineers. Engineers need to look at shock trials as an opportunity for improving systems and not as just another problem to solve. If we are truly going to build a capable fighting Navy, we must take every chance we have and build on it.

CONCLUSIONS

After many years of conducting ship shock tests the Navy is now ready to demonstrate that the lessons learned have been applied and that installed systems will perform as required in a combat shock environment. Ship shock trials are here to stay. As shown in figure 2, there will be plenty of opportunities to demonstrate system capabilities. There is much work for equipment and system engineers. Building on the lessons learned, a system approach for shock hardening must now be utilized. Now is the time for system and equipment designers to stop relying on "someone else" such as QA inspectors or ships force, to remove potential post delivery shock problems. Designers must now "design out" the vulnerability to QA and maintenance factors. Attention needs to be paid to wartime priorities rather than peacetime requirements. By doing so, we can create "Peaceshorts" as opposed to "Battleshort" and Combat Readiness Cards. Equipment and systems engineers must redefine their objectives so that combat performance is foremost in their minds. By taking the approach that ship shock trials can be a benefit, the designer can provide fully demonstrated shock capable systems to the fleet. Finally now is the time to proceed in an orderly fashion and to provide the shock capability when it is truly needed.

Figure 1

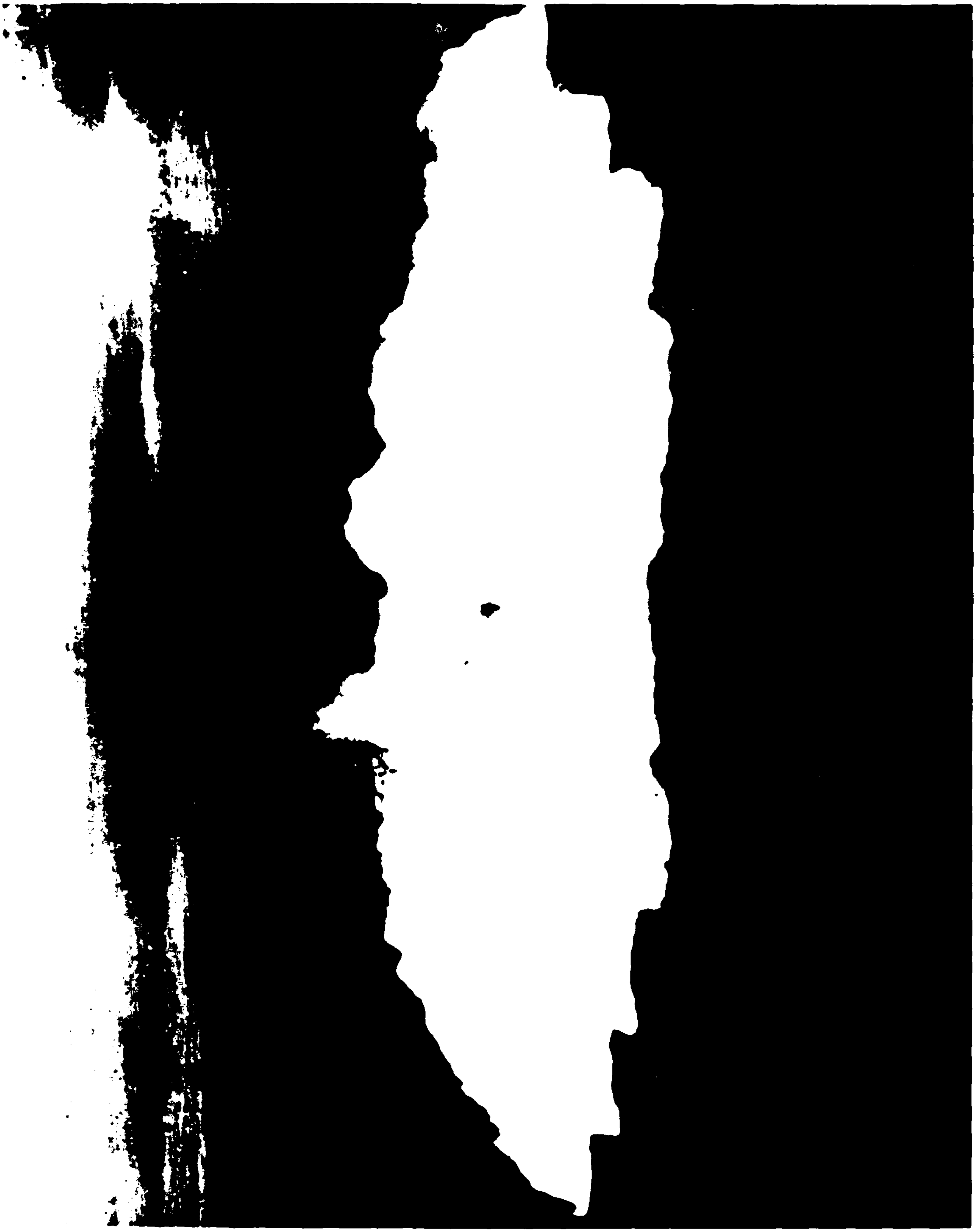

Figure 2

SHIP SHOCK TRIAL SCHEDULE

USS MOBILE BAY	CG 53	SPRING 1987
USS THEODORE ROOSEVELT	CVN 71	FALL 1987
USS KAUFFMAN	FFG 59	FALL 1987
GUNSTON HALL	LSD 44	SPRING 1989
SENTRY	MCM 3	SUMMER 1989
WASP	LHD 1	FALL 1989
ARLEIGH BURKE	DDG 51	SPRING 1991
SUPPLY	AOE 6	1991
USS BRISCOE	DD(G) 977	1991

FIGURE 3

SHOCK WAVE CHARACTERISTICS

A shock wave is instantaneously created and travels through the seawater in all direction.

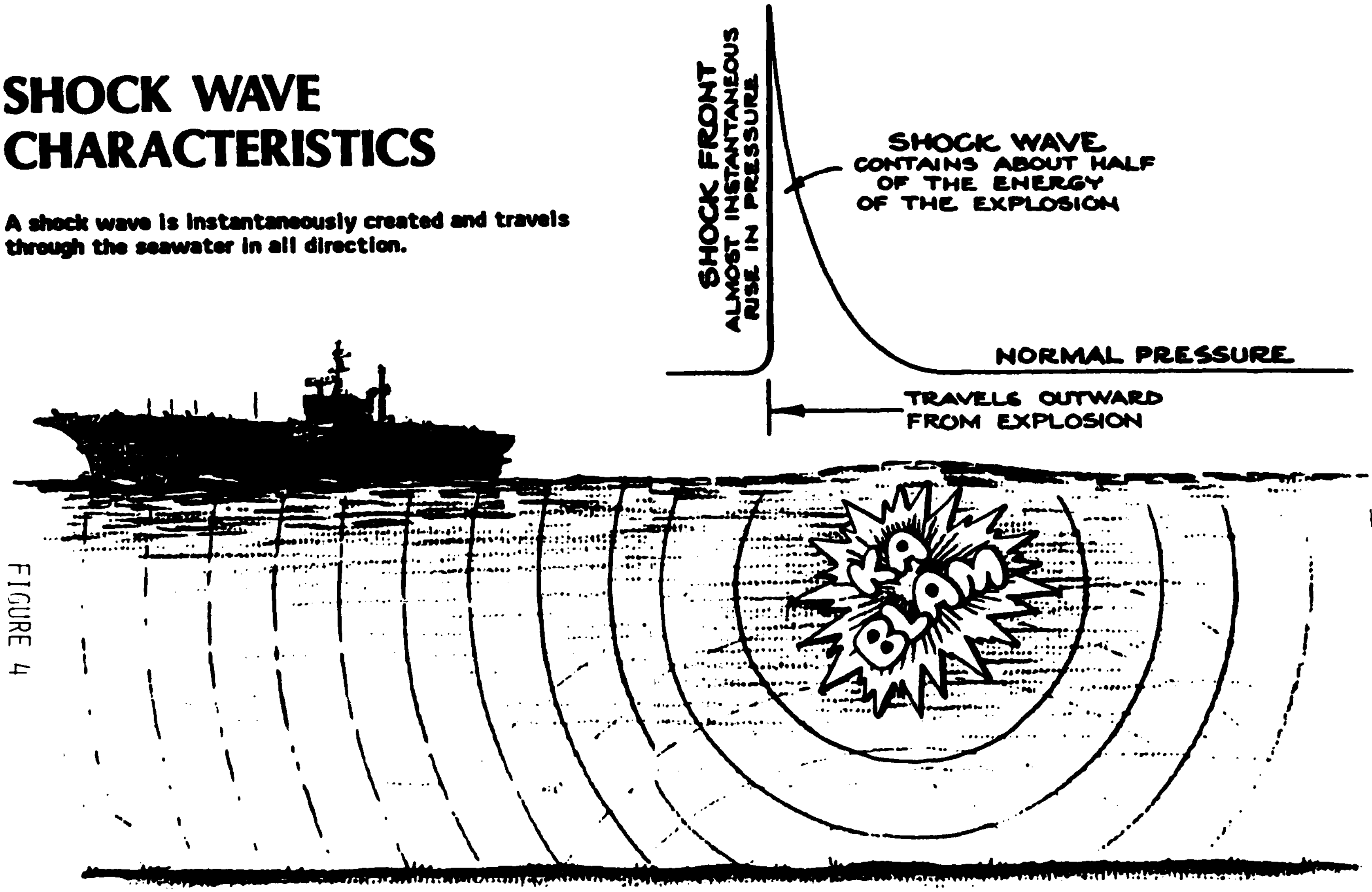

FIGURE 4

DAMAGE CONTROL CONSIDERATIONS

Almost everyone is familiar with the unofficial "ten commandments of damage control".

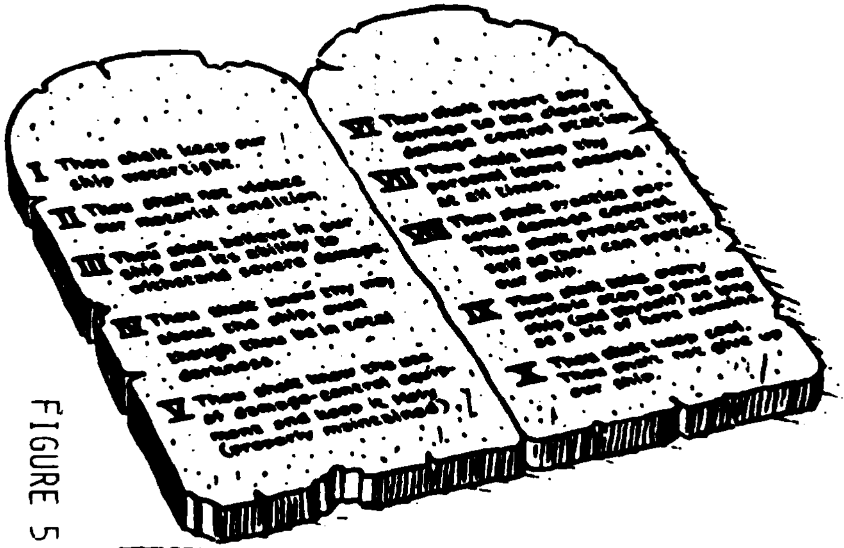

FIGURE 5

THE TEN COMMANDMENTS of DAMAGE CONTROL

These guidelines still apply in the combat shock situation; but underwater shock damage creates special problems which makes damage control somewhat different than what you may be used to.

FACTORS WHICH MAKE COMBAT SHOCK DAMAGE CONTROL DIFFERENT

- **"Drill mentality" is absent.**
- **Damage is real!**
- **"Pucker factor" exists prior to and during the event.**
- **Shipwide, multiple casualties will occur.**
- **Different types of casualties will occur nearly simultaneously (i.e., possibly fire, flooding, and loss of electrical power) following the shock.**

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